Energy Flow with high granularity calorimeters[1]

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Abstract. In order to perform high precision measurements as well as search for new phenomena at a next Linear Collider, excellent ENERGY FLOW is mandatory. High granularity calorimeters design will fulfill the requests and preliminary results are presented as well as further directions to reach the final performances.

Introduction and concepts

Beside processes with a clear signature as photon final state, most of the reactions produced at the Next e^+e^- Linear Collider energies are characterized by muti-jets final states and the detectors should be designed to explore these topologies. Therefore a dedicated jet reconstruction algorithm, ENERGY FLOW, have to be developed to achieve the requested performances.

The background machine imposes a large magnetic field (~4T) produced by a $\sim 2\lambda_I$ thickness coil; thus, compact calorimeters (ECAL and HCAL) have to be instold inside the coil. In other hand, the requests given by the Physics are hermeticity, lepton ID and jet reconstruction. About the latter point, the energy and angular resolutions of the calorimeters have to be excellent anyway, but they have to be optimized also for the particle reconstruction. As an illustration, the resolution on visible mass observed at $\sqrt{s}$=91.2 GeV with the ALEPH detector at LEP was 6.5 GeV/c^2, with 3. GeV/c^2 and 5.5 GeV/c^2 coming from the resolution and the imperfect reconstruction of the particles respectively. Due to increase of dead zones in end-caps, this resolution strongly depends of the jet angle. Thus, to avoid such a behavior, a great minimization of the cracks have to be achieved as well as a geometry as uniform as possible. Then, the design of the calorimeters is driven by compactness, uniformicity, hermeticity, small pad size and high granularity. In other hand, the test of the design is delivered by the performances of the ENERGY

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[1] work resulting of the contributions from JC. Brient, P. Cloarec, V. Djordjadze, P. Mora de Freitas, F. Le Diberder, S. Monteil, D. Orlando, D. Reid and H. Videau

FLOW algorithm and it is genuine part of the detector design. Two calorimeters has been designed to fulfill the previous requests : a Si-W sampling electromagnetic calorimeter and a 3D-Digital hadronic calorimeter. They share the same small (1×1 cm^2) pad size and the high longitudinal sampling consist on 40 layers in each calorimeters. The geometries of Si-W ECAL and 3D-digital HCAL are described in Ref. [1].

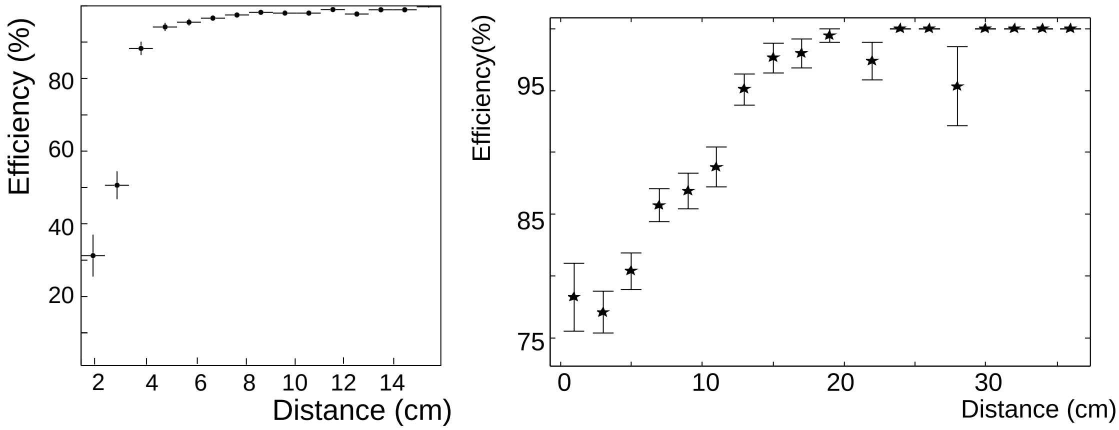
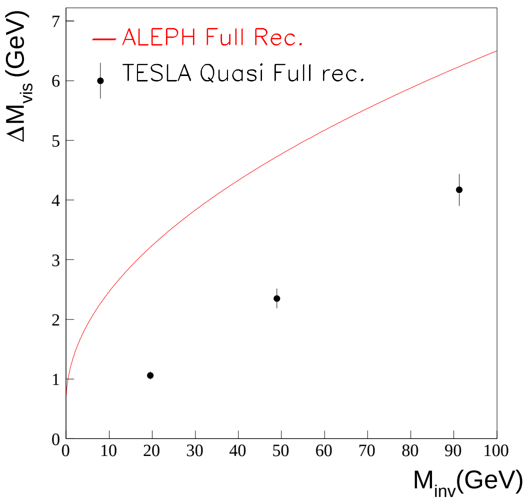


FIGURE 1. (left) Photon reconstruction efficiency as a function of the distance to the charged track; **(right)** Neutral hadron efficiency as a function of distance from the charged hadron.

Jet reconstruction

The jet reconstruction is based on a analytic ENERGY FLOW algorithm where the reconstruction of the photon, neutral hadron and charged particle contributions are provided thanks to the reconstruction methods developed in Ref. [2]. This implies photon and neutral hadron reconstruction with rejection of the debris from charged hadron interaction. The studies of the high granularity calorimeters design lead to very good performances with single particles as well as with jet reconstruction. Even in difficult situations, the separation between photon and neutral hadron from charged hadron is possible as indicated by the results displayed on Fig. 1 [2].

Z decays in two jets events at a centre-of-mass energy of 91.2 GeV have been simulated [3] with the actual geometry for both ECAL and 3D-HCAL. With a full reconstruction in the calorimeters a resolution of 4.2 GeV/c^2 is obtained on the visible energy measurement of the di-jets events. It has been shown that the result of the full simulation could be reflected by a fast-simulation if such a simulation takes into account three terms : 1) the efficiency reconstruction, 2) energy and direction resolutions of the photon or neutral hadron and 3) the corresponding fake rate. These quantities have to be defined as function of the energy and of the distance to the charged hadron according the results obtained from full reconstruction on benchmark tests. A so-called quasi-full reconstruction has been also developed. It consists on the full reconstruction of the objects in the calorimeters except for neutral hadron which are treated similarly to the fast-simulation. This quasi-full reconstruction has been used to derive the expected resolution on visible masses; the resolution obtained with the Z decays events at $\sqrt{s}$=91.2 GeV is 4.1 GeV/c^2 in agreement with the full reconstruction result. The comparison with the ALEPH detector performances is displayed on Fig. 2 for different jets samples. The improvement due to the high granularity and uniformity is clearly observed.



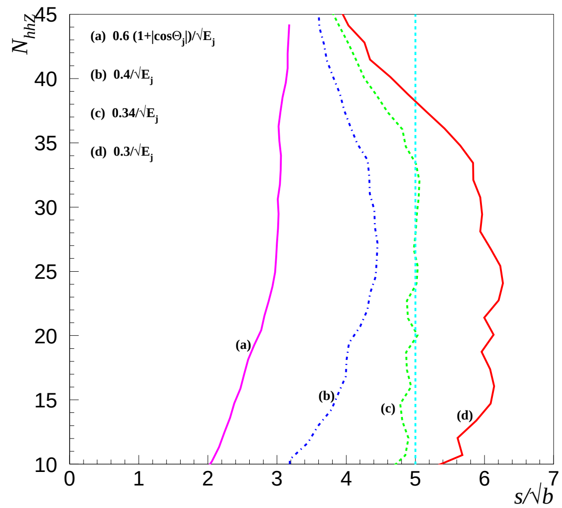


FIGURE 2. (left) Resolution on the visible mass as a function of the invariant mass obtained with a quasi-full reconstruction of the jets in high granularity calorimeters (dots); results obtained with the ALEPH detector (full line) are also indicated for comparison. **(right)** Number of expected $e^+e^-\to$hhZ$\to$6 jets events as a function of the figure of merit defined as $s/\sqrt{b}$, for different choices of ENERGY FLOW jet resolutions including the angular dependence in case of choice quoted (a); m_h=120 GeV/c^2 and an integrated luminosity of 1000 fb^{-1} have been assumed.

In order to illustrate the impact of the ENERGY FLOW resolution on multi-jets final state, a specific analysis of hhZ leading to the trilinear Higgs coupling measurement has been used [4]. The number of signal event expected with an integrated luminosity of 1000 fb^{-1} at centre-of-mass energy of 500 GeV is displayed as a function of the figure of merit ($s/\sqrt{b}$) on Fig. 2. The comparison of different ENERGY FLOW resolutions indicates that a resolution better than $35\%/\sqrt{E_{jet}}$ is a powerful (and mandatory) tool in multijets analysis. This can be generalized to other multijets final states and emphasizes the importance of a very high granularity calorimeter with an excellent coverage.

Prospects

The previous results did not represent the ultimate performances. Beside the standard approaches [2], alternatives have been investigated. These studies have been done in a framework of a projective geometry of the calorimeters [3]. In contrast with clustering approach where a pad belong only one cluster, a probabilistic approach has been adopted (EMILE[2]). It is based on real 3D geometry and takes into account the long range interaction. In particular, a pad could be shared between different closed 'objects'. With EMILE an clusterisation efficiency of 96% is obtained with 100 MeV photons. This method is particularly interesting for low energy photon in hostile environment as charged hadrons. The high granularity of both ECAL and HCAL allows also pattern recognition. Such a method is used to reconstruct the different 'tracks' produced by charged hadrons observed in the calorimeters. The 'vertex' of such 'tracks' is also reconstructed and is used to classify the 'objects' as photon or hadron elements. The method has been tested with 1 GeV photon close to charged hadrons (10 GeV π^+). The orientation of the 4 T magnetic field has been choosen in such a way that the overlapping between the showers induced by the photon and the charged hadron is maximal. Efficiencies of 40%, 67% and 84% have been obtained for distance between the two particles (photon and π^+) at the ECAL entrance of 1, 2 and 3 cm respectively, with a fake rate of 15%.

A closer look to the ENERGY FLOW resolution of 4.2 GeV/c^2, previously quoted, indicates that the main contribution is coming from the imperfect reconstruction of the neutral hadron. EMILE algorithm could be extended in the framework of the actual geometry to such a reconstruction and will participate to the foreseen improvement.

Conclusions

The reconstruction of the jets based on full simulation leads to an energy resolution of $40\%/\sqrt{E_{jet}}$ which presents a great improvement with respect to the detectors from the previous generation like those implemented on LEP Collider. The multi-jet final state will play an important role in the next Linear Collider Physics and an ENERGY FLOW jet resolution better than $35\%/\sqrt{E_{jet}}$ is necessary. The high granularity calorimeter design allows ENERGY FLOW algorithm performances which could match such a request.

REFERENCES

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3. P. Mora de Freitas, *Calorimeter studies with GEANT4* , these proceedings
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2) Energy Measurement Intended for Low Energy showers